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(54) **[Title of the Invention]** ZOOM LENS

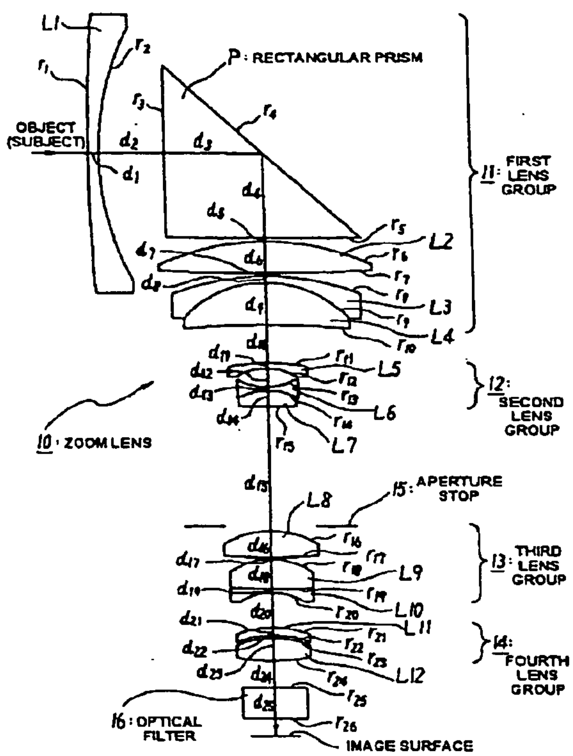
(57) **[Abstract]**

[Objects] To provide a zoom lens that permits more freedom in the design of a video camera without making it thicker or longer and that has a small front lens diameter despite offering a wide angle of view at the wide-angle end.

[Features] A zoom lens 10 is composed of, from the object side, a first lens group 11 having a positive refractive power, a second lens group 12 having negative refractive power, an aperture stop 15, a third lens group 13 having a positive refractive power, and a fourth lens group 14 having a positive refractive power. The first and second lens groups 11 and 12 constitute a zooming system. The first lens group 11 is composed of, from the object side, a concave lens element L1, a rectangular prism P, a convex lens element L2, and a cemented lens element having a concave lens element L3 and a convex lens element L4 cemented together. The optical axis of the rays from an object is bent at a right angle by the rectangular prism P, and this greatly reduces the length in the direction of the incident optical axis. The interposition of the rectangular prism P increases the distance between the

concave lens element L1 and the group of the lens elements L2 to L4, and thus puts the image-side principal point of the first lens group 11 backward. This helps shorten the focal length of the first lens group 11, and is therefore advantageous for wide-angle shooting.

CONSTRUCTION OF EMBODIMENT



[Claims]

[Claim 1] A zoom lens comprising, from an object side, a zooming system composed of a first lens group having a positive refractive power and a second lens group having a negative refractive power, an aperture stop, a third lens group having a positive refractive power and kept stationary, and a fourth lens group having a positive refractive power and movable for adjustment of a focal position as when zooming is performed and when a subject distance varies,

wherein the first lens group is composed of, from the object side, a first concave lens element, a rectangular prism, a first convex lens element, and a cemented lens element having a second concave lens element and a second convex lens element cemented together.

[Claim 2] A zoom lens as claimed in claim 1, wherein the first lens group substantially fulfills the following conditions (1) and (2) :

(1) $1.72 < n_1$

(2) $-7 < \nu_1 - \nu_2 < 15$

where n_1 represents a refractive index for the e-line of the medium of the first concave lens element,

ν_1 represents an Abbe number for the e-line of the medium of the first concave lens element, and

ν_2 represents an Abbe number for the e-line of the medium of the first convex lens element.

[Claim 3] A zoom lens as claimed in claim 1, wherein the first lens group substantially fulfills the following condition (1):

(1) $1.65 < n_P$

where n_P represents a refractive index for the e-line of the medium of the rectangular prism.

[Claim 4] A zoom lens as claimed in claim 1, wherein the image-side surface of the second convex lens element provided in the first lens group is an aspherical surface

[Detailed Description of the Invention]

[0001]

[Field of the Invention] The present invention relates to a zoom lens suitable for use in, for example, a video camera. More particularly, the present invention relates to a zoom lens in which the first lens group constituting part of the zooming system is composed of a first concave lens element, a rectangular prism, a first convex lens element, and a cemented lens element having a second concave lens element and a second convex lens element cemented together so that the zoom lens has a greatly reduced length in the direction of the incident

optical axis and has a small front lens diameter despite offering a wide angle of view at the wide-angle end.

[0002]

[Prior Art] Nowadays, most zoom lenses for use in video cameras are of the so-called inner-focus type that has a positive-negative-positive-positive refractive power arrangement as a whole, that has an aperture stop disposed immediately in front of the third, stationary, lens group, that moves the second, negative, lens group mainly to perform zooming, and that moves the fourth, positive, lens group to adjust the focal position. Using zoom lenses of this inner-focus type helps miniaturize video cameras as compared with using zoom lenses of the conventional so-called front-lens-protracting type (see Japanese Patent Application Laid-Open No. H3-33710).

[0003]

[Problems to be Solved by the Invention] It is true that using a zoom lens of the inner-focus type helps achieve miniaturization, but the effect of adopting this type, combined with the effect brought about by the use of aspherical-surface lens elements, is reducing the total length of the zoom lens to about 70 %, at best, of the total length of a comparable zoom lens of the front-lens-protracting type. Thus, if the thickness of an image sensor and the thickness of a circuit board placed behind the image sensor are taken into consideration, adopting the inner-focus type does not contribute so much to miniaturization of the video camera as a whole as it contributes to reduction of the total length of the optical system. The design of a video camera depends almost totally on the arrangement of a mechanical deck, a battery, and a lens. Placing the lens at the side of the mechanical deck, which is rectangular, results in a thick design, and placing the lens at the front of the mechanical deck results in a slim but elongate design.

[0004] An object of the present invention is to provide a zoom lens that permits more freedom in the design of a video camera without making it thicker or longer. Another object of the present invention is to overcome the disadvantage of a high-magnification zoom lens for a video camera, which tends to have a narrow angle of view at the wide-angle end as compared with a standard zoom lens for a still camera.

[0005]

[Means for Solving the Problem] According to the present invention, a zoom lens is composed of, from the object side, a zooming system composed of a first lens group having a positive refractive power and a second lens group having a negative refractive power, an aperture stop, a third lens group having a positive refractive power and kept stationary, and a

fourth lens group having a positive refractive power and movable for adjustment of the focal position as when zooming is performed and when the subject distance varies. Here, the first lens group is composed of, from the object side, a first concave lens element, a rectangular prism, a first convex lens element, and a cemented lens element having a second concave lens element and a second convex lens element cemented together.

[0006]

[Working] The rays from an object (subject) pass through the first concave lens element provided in the first lens group, then have their optical axis bent at a right angle by the rectangular prism, and then passes through the first convex lens element and the cemented lens element having the second concave lens element and the second convex lens element cemented together, all provided in the first lens group, so as to be incident on the second lens group. The first concave lens element permits the principal rays to be incident on the rectangular prism with smaller inclination angles. Interposing the rectangular prism between the first concave lens element and the group of the first convex, second concave, and second convex lens elements, which as a whole has a positive refractive power, helps increase the interval there and thereby put the image-side principal point of the first lens group backward.

[0007]

[Embodiments of the Invention] Hereinafter, with reference to Fig. 1, a zoom lens embodying the invention will be described. The zoom lens 10 embodying the invention is composed of, from the object side, a first lens group 11 having a positive refractive power, a second lens group 12 having a negative refractive power, an aperture stop 15, a third lens group 13 having a positive refractive power, and a fourth lens group 14 having a positive refractive power. The first and second lens groups 11 and 12 constitute a zooming system, and zooming is achieved by moving the second lens group 12. Moreover, by moving the fourth lens group 14, the focal position is adjusted as when zooming is performed and when the subject distance varies. Between the fourth lens group 14 and the image surface, there is disposed an optical filter 16.

[0008] The first lens group 11 is composed of, from the object side, a concave lens element L1, a rectangular prism P, a convex lens element L2, and a cemented lens element having a concave lens element L3 and a convex lens element L4 cemented together. The rectangular prism P acts to bend at a right angle the optical axis of the rays that have passed through the concave lens element L1. The convex lens element L4 is a spherical-surface lens element in Example 1, which will be described later, but it has an aspherical surface on the image side thereof in Example 2, which will be described later. The second lens group 12 is composed

of, from the object side, a concave lens element L5, a concave lens element L6, and a convex lens element L7.

[0009] The third lens group 13 is composed of, from the object side, a convex lens element L8, a convex lens element L9, and a concave lens element L10. The convex lens element L8 has an aspherical surface on the object side thereof. The fourth lens group 14 is composed of, from the object side, a lens element L11 having a weak refractive power and a biconvex lens element L12. The lens element L11 is made of plastic, and has an aspherical surface on the image side thereof. The lens element L11 has a very weak refractive power, and is thin. Thus, errors in the surface accuracy of the lens element L11 resulting from contraction in the molding process or from variations in temperature do not seriously affect performance. This helps reduce costs and obtain high performance simultaneously.

[0010] On the basis of experiment results and other data, the zoom lens 10 embodying the invention is so constructed as to fulfill conditions (1) to (3) below. It may be so constructed as to fulfill either conditions (1) and (2) simultaneously or condition (3) alone.

[0011] (1) $1.72 < n_1$

(2) $-7 < \nu_1 - \nu_2 < 15$

(3) $1.65 < n_P$

where n_1 represents the refractive index for the e-line of the medium of the concave lens element L1,

ν_1 represents the Abbe number for the e-line of the medium of the concave lens element L1,

ν_2 represents the Abbe number for the e-line of the medium of the convex lens element L2, and

n_P represents the refractive index for the e-line of the medium of the rectangular prism P.

[0012] Condition (1) is a condition that needs to be fulfilled to satisfactory reduce the barrel-shaped distortion produced by the concave lens element L1, through which the principal rays pass at the greatest heights at the wide-angle end. By making the refractive index n_1 higher, it is possible to make the curvature of the surface r_2 gentler and thereby make it easier to correct distortion.

[0013] Condition (2) relates to the correction of lateral chromatic aberration at the wide-angle end. The lateral chromatic aberration produced by the concave lens element L1 needs to be corrected by the convex lens element L2, through which the principal rays pass at comparatively great heights. When the glass material of the concave lens element L1 is determined on the basis of condition (1), the cost of the glass material, and other factors, with respect to lateral chromatic aberration, if the Abbe number of the convex lens element L2 is

below the lower limit, the g-line smears inward, and, if it is above the higher limit, the g-line smears outward and in addition it is difficult to correct longitudinal chromatic aberration at the telephoto end.

[0014] Condition (3) is for achieving total reflection in the rectangular prism P. By making the refractive index n_P of the rectangular prism P higher, it is possible to reduce the inclination angles of the principal rays inside the rectangular prism P at the wide-angle end and increase the critical angle of incidence in order to achieve total reflection and thereby minimize loss of light.

[0015] In the construction described above, the rays from the object (subject) pass through the concave lens element L1 provided in the first lens group 11, then have their optical axis bent at a right angle by the rectangular prism P, and then pass through the convex lens element L2 and the cemented lens element having the concave lens element L3 and the convex lens element L4 cemented together, all provided in the first lens group 11. The rays then pass through the second lens group 12, the aperture stop 15, the third lens group 13, the fourth lens group 14, and the optical filter 16, and reach the image surface. Here, the rectangular prism P bends the optical axis once, and thus the image formed on the image sensor is reversed left to right or inverted upside down. In a video camera or the like, the image can easily be put back to an erect, right image.

[0016] Hereinafter, as numerical examples, Examples 1 and 2 will be presented. In these numerical examples, ri (i = 1 to 26) represents the radius of curvature [mm] of the i-th surface, di (i = 1 to 25) represents the i-th axial distance [mm], nj (j = 1 to 13) represents the refractive index for the e-line of the j-th medium, νj (j = 1 to 13) represents the Abbe number for the e-line of the j-th medium, np represents the refractive index for the e-line of the medium of the rectangular prism P, and the νp represents the Abbe number for the e-line of the medium of the rectangular prism P.

[0017] [Example 1]

A. (the radius of curvature of each surface, the interval between every two adjacent surfaces, the refractive index of each medium, and the Abbe number of each medium)

r_1	400.	d_1	1.	n_1	1.83930	ν_1	37.1
r_2	38.253	d_2	4.3				
r_3	∞	d_3	10.	n_P	1.70559	ν_P	40.9
r_4	∞	d_4	9.5	n_P	1.70559	ν_P	40.9
r_5	∞	d_5	1.				
r_6	61.845	d_6	2.75	n_2	1.83930	ν_2	37.1

r_7	-61.845	d_7	0.2				
r_8	16.539	d_8	0.75	n_3	1.85505	ν_3	23.6
r_9	10.101	d_9	4.815	n_4	1.69980	ν_4	55.3
r_{10}	62.756	d_{10}					
r_{11}	94.821	d_{11}	0.5	n_5	1.83930	ν_5	37.1
r_{12}	5.389	d_{12}	1.72				
r_{13}	-6.762	d_{13}	0.5	n_6	1.66152	ν_6	50.6
r_{14}	7.132	d_{14}	1.823	n_7	1.85505	ν_7	23.6
r_{15}	-32.461	d_{15}					
r_{16}	7.096	d_{16}	4.183	n_8	1.69661	ν_8	53.0
r_{17}	-25.713	d_{17}	0.2				
r_{18}	20.07	d_{18}	2.064	n_9	1.51872	ν_9	64.0
r_{19}	-29.137	d_{19}	0.5	n_{10}	1.85505	ν_{10}	23.6
r_{20}	7.517	d_{20}					
r_{21}	10.	d_{21}	0.8	n_{11}	1.494	ν_{11}	56.8
r_{22}	10.	d_{22}	0.2				
r_{23}	8.167	d_{23}	2.943	n_{12}	1.51872	ν_{12}	64.0
r_{24}	-13.305	d_{24}					
r_{25}	∞	d_{25}	3.32	n_{13}	1.55898	ν_{13}	58.3
r_{26}	∞						

[0018]

B. (aspherical surface coefficients)

Coefficients	A_4	A_6	A_8	A_{10}
Surface r_{16}	-0.3923×10^{-3}	-0.4897×10^{-5}	0.3836×10^{-7}	-0.3000×10^{-8}
Surface r_{22}	0.9229×10^{-3}	0.1212×10^{-4}	-0.4148×10^{-8}	0.1810×10^{-8}

An aspherical surface is defined by

$\chi_i = H^2 / r_i \{1 + (1 - H^2 / r_i^2)^{1/2}\} + \Sigma A_j H^j$

where χ_i represents the depth of the aspherical surface, and

H represents the height from the optical axis.

[0019] C. (positions of the aperture stop and the focal point)

The aperture stop is located at 0.7 mm in front of surface r_{16}, and the focal point is located at 2.0 mm behind surface r_{26}.

[0020] D. (distances between surfaces that vary with the focal length f[mm])

Focal Length f	3.72	14.296	28.644

f-number	1.43	1.92	2.35
d_{10}	0.9	10.172	13.507
d_{15}	14.757	5.485	2.15
d_{20}	3.884	1.441	3.874
d_{24}	2.213	4.657	2.223

[0021] Figs. 2, 3, and 4 show the spherical aberration, astigmatism, and distortion observed when f = 3.72, when f = 14.296, and when f = 28.644, respectively. That is, Figs. 2, 3, and 4 show the aberrations observed at the wide-angle end, at the middle focal length, and at the telephoto end, respectively. In Figs. 2 to 4, the solid line "e" represents the spherical aberration for the e-line, the dash-dot line "c" represents the spherical aberration for the c-line, and the broken line "g" represents the spherical aberration for the g-line. In Figs. 2 to 4, the solid line "S" represents the astigmatism on the sagittal plane, and the broken line "M" represents the astigmatism on the meridional plane. F represents the f-number, and ω represents the half view angle.

[0022] [Example 2]

A. (the radius of curvature of each surface, the interval between every two adjacent surfaces, the refractive index of each medium, and the Abbe number of each medium)

r_1	315.511	d_1	1.	n_1	1.77621	ν_1	49.4
r_2	35.068	d_2	6.464				
r_3	∞	d_3	10.	n_P	1.70559	ν_P	40.9
r_4	∞	d_4	9.5	n_P	1.70559	ν_P	40.9
r_5	∞	d_5	0.5				
r_6	25.67	d_6	3.62	n_2	1.83930	ν_2	37.1
r_7	-270.691	d_7	0.2				
r_8	24.568	d_8	0.75	n_3	1.85505	ν_3	23.6
r_9	11.111	d_9	4.702	n_4	1.69661	ν_4	53.0
r_{10}	75.94	d_{10}					
r_{11}	20.69	d_{11}	0.5	n_5	1.83962	ν_5	42.8
r_{12}	5.469	d_{12}	2.064				
r_{13}	-6.748	d_{13}	0.5	n_6	1.66152	ν_6	50.6
r_{14}	7.407	d_{14}	1.765	n_7	1.85505	ν_7	23.6
r_{15}	-80.117	d_{15}					
r_{16}	8.771	d_{16}	2.897	n_8	1.69661	ν_8	53.0
r_{17}	-79.477	d_{17}	0.2				

r_{18}	7.106	d_{18}	3.111	n_9	1.51978	ν_9	51.9
r_{19}	-66.263	d_{19}	0.5	n_{10}	1.85505	ν_{10}	23.6
r_{20}	5.762	d_{20}					
r_{21}	10.	d_{21}	0.8	n_{11}	1.494	ν_{11}	56.8
r_{22}	10.	d_{22}	0.2				
r_{23}	7.657	d_{23}	2.691	n_{12}	1.51872	ν_{12}	64.0
r_{24}	-16.529	d_{24}					
r_{25}	∞	d_{25}	3.32	n_{13}	1.55898	ν_{13}	58.3
r_{26}	∞						

[0023]

B. (aspherical surface coefficients)

Coefficients	A_4	A_6	A_8	A_{10}
Surface r_{10}	0.1383×10^{-4}	0.4175×10^{-7}		
Surface r_{16}	-0.1518×10^{-3}	-0.1521×10^{-5}		
Surface r_{22}	0.9186×10^{-3}	-0.1178×10^{-4}	0.1273×10^{-5}	-0.2186×10^{-7}

[0024] C. (positions of the aperture stop and the focal point)

The aperture stop is located at 0.7 mm in front of surface r_{16}, and the focal point is located at 2.0 mm behind surface r_{26}.

[0025] D. (distances between surfaces that vary with the focal length f[mm])

Focal Length f	3.72	17.336	35.711
f-number	1.63	1.88	2.55
d_{10}	0.9	12.482	16.214
d_{15}	17.464	5.882	2.15
d_{20}	4.826	1.555	4.816
d_{24}	2.104	5.285	2.024

[0026] Figs. 5, 6, and 7 show the spherical aberration, astigmatism, and distortion observed when f = 3.72, when f = 17.336, and when f = 35.711, respectively. That is, Figs. 5, 6, and 7 show the aberrations observed at the wide-angle end, at the middle focal length, and at the telephoto end, respectively. In Figs. 5 to 7, the solid line "e" represents the spherical aberration for the e-line, the dash-dot line "c" represents the spherical aberration for the c-line, and the broken line "g" represents the spherical aberration for the g-line. In Figs. 5 to 7, the solid line "S" represents the astigmatism on the sagittal plane, and the broken line "M" represents the astigmatism on the meridional plane. F represents the f-number, and ω represents the half view angle.

[0027] As described above, in the zoom lens 10 embodying the invention, the optical axis is bent at a right angle by the rectangular prism P provided in the first lens group 11. This helps greatly reduce the length in the direction of the incident optical axis. Thus, when it is used in, for example, a video camera, by disposing it in front of the mechanical deck, which is rectangular, it is possible to make the video camera neither thick nor elongate.

[0028] The zoom lens 10 embodying the invention has a small front lens diameter despite having a wide angle of view at the wide-angle end. Specifically, the principal rays have their inclination angles made smaller by the concave lens element L1 before entering the rectangular prism P. This permits the use of a small rectangular prism P despite a wide angle of view. Moreover, interposing the rectangular prism P between the concave lens element L1 and the group of the lens elements L2, L3, and L4, which has a positive refractive power as a whole, helps increase the interval there and thereby put the image-side principal point of the first lens group 11 backward. This helps shorten the focal length of the first lens group 11, and is thus advantageous for wide-angle shooting.

[0029] If the rectangular prism P is disposed in front of a conventional zoom lens, it is necessary to use a rectangular prism P that covers the required angle of view, and making the zoom lens wide-angle necessitates an extremely large rectangular prism P. If the rectangular prism P is disposed between the first and second lens groups 11 and 12 with the interval there increased, the principal rays have larger inclination angles between the first and second lens groups 11 and 12 than their incident inclination angles, and this requires a still larger rectangular prism P. If the rectangular prism P is disposed behind the movement space of the second lens group 12, it is impossible to greatly reduce the length of the incident optical axis.

[0030] Moreover, in the zoom lens 10 embodying the invention, the convex lens element 14 provided in the first lens group 11 has an aspherical surface on the image side thereof. This makes it possible to reduce the total lens length as measured with the optical axis bent and achieve a high-magnification zoom ratio simultaneously. Specifically, if a high zoom ratio combined with a small movement stroke of the second lens group 12 is attempted by giving the first and second lens groups 11 and 12 stronger refractive powers, it is difficult to correct the spherical aberration and coma produced by the first lens group 11 at the telephoto end. This can be avoided effectively by using an aspherical surface in the first lens group 11 and making it aspherical in such a direction as to correct spherical aberration of the type undercorrected with respect to a paraxial spherical surface. A similar effect is achieved by introducing an aspherical surface in one of the lens elements L2, L3, and L4, through which a

wide beam passes, but giving the convex lens element L4 an aspherical surface makes the aspherical surface easy and inexpensive to produce.

[0031]

[Advantages of the Invention] According to the present invention, the first lens group constituting part of the zooming system is composed of a first concave lens element, a rectangular prism, a first convex lens element, and a cemented lens element having a second concave lens element and a second convex lens element cemented together. This helps greatly reduce the length in the direction of the incident optical axis. Thus, when it is used in,. for example, a video camera, by deposing it in front of the mechanical deck, which is rectangular, it is possible to make the video camera neither thick nor elongate and thereby increase freedom in design.

[0032] Moreover, the rectangular prism is disposed between the first concave lens element and the first convex lens element, and thus the principal rays have their inclination angles made smaller by the first concave lens element before entering the rectangular prism. This permits the use of a small rectangular prism despite a wide angle of view. In addition, interposing the rectangular prism between the first concave lens element and the group of the first convex lens element, second concave lens element, and second convex lens element, which has a positive refractive power as a whole, helps increase the interval there and thereby put the image-side principal point of the first lens group 11 backward. This helps shorten the focal length of the first lens group, and is thus advantageous for wide-angle shooting. In this way, it is possible to make the front lens diameter small despite of a wide angle of view.

[Brief Description of the Drawings]

[Fig. 1] A diagram showing the construction of a zoom lens embodying the invention

[Fig. 2] A diagram showing the spherical aberration, astigmatism, and distortion observed in Example 1, at the wide-angle end.

[Fig. 3] A diagram showing the spherical aberration, astigmatism, and distortion observed in Example 1, at the middle focal length.

[Fig. 4] A diagram showing the spherical aberration, astigmatism, and distortion observed in Example 1, at the telephoto end.

[Fig. 5] A diagram showing the spherical aberration, astigmatism, and distortion observed in Example 2, at the wide-angle end.

[Fig. 6] A diagram showing the spherical aberration, astigmatism, and distortion observed in Example 2, at the middle focal length.

[Fig. 7] A diagram showing the spherical aberration, astigmatism, and distortion observed in Example 2, at the telephoto end.

[Description of the Reference Designations]

10 zoom lens

11 first lens group

12 second lens group

13 third lens group

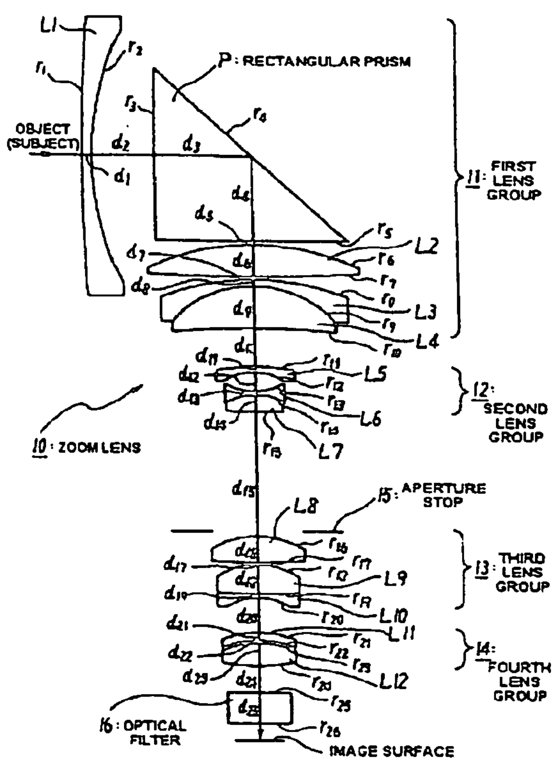
14 fourth lens group

15 aperture stop

16 optical filter

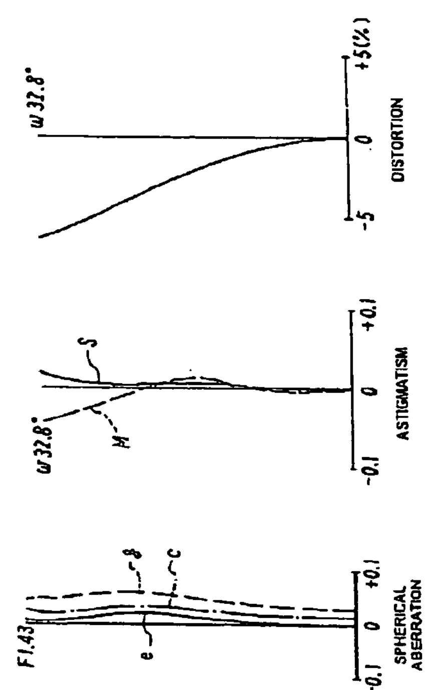
[Fig. 1]

CONSTRUCTION OF EMBODIMENT



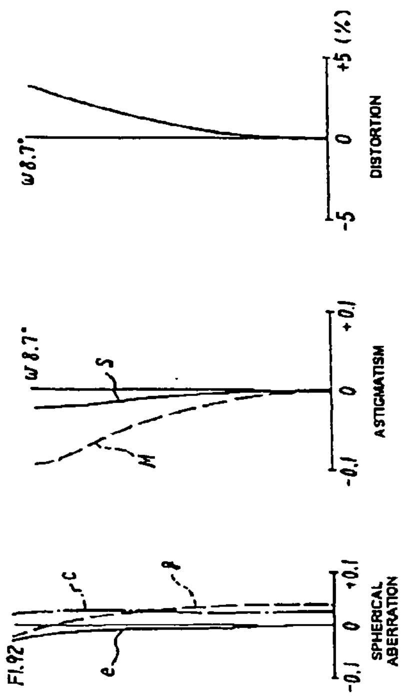
[Fig. 2]

SPHERICAL ABERRATION, ASTIGMATISM, AND DISTORTION IN EXAMPLE 1 AT WIDE-ANGLE END



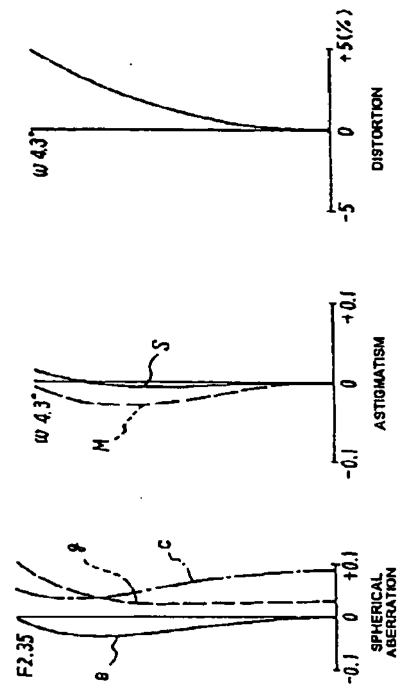
[Fig. 3]

SPHERICAL ABERRATION, ASTIGMATISM, AND DISTORTION IN EXAMPLE 1 AT MIDDLE



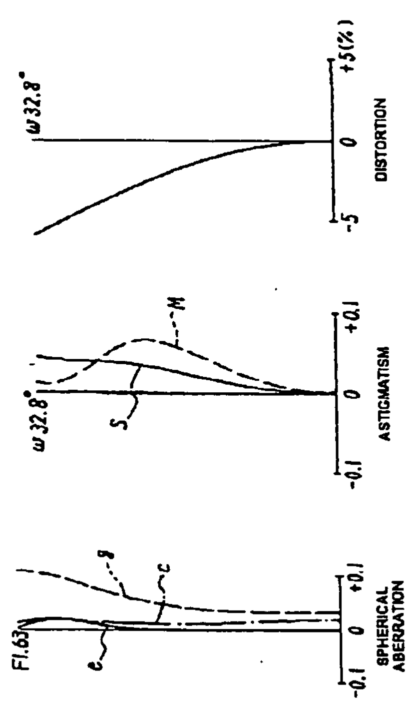
[Fig. 4]

SPHERICAL ABERRATION, ASTIGMATISM, AND DISTORTION IN EXAMPLE 1 AT TELEPHOTO END



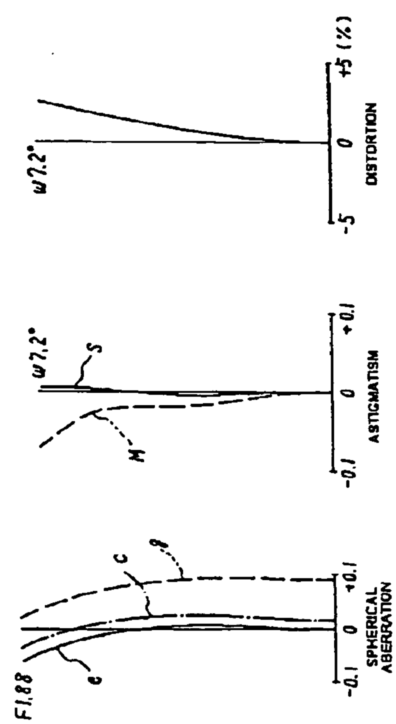
[Fig. 5]

SPHERICAL ABERRATION, ASTIGMATISM, AND DISTORTION IN EXAMPLE 1 AT WIDE-ANGLE END



[Fig. 6]

SPHERICAL ABERRATION, ASTIGMATISM, AND DISTORTION IN EXAMPLE 1 AT MIDDLE



[Fig. 7]

SPHERICAL ABERRATION, ASTIGMATISM,
AND DISTORTION IN EXAMPLE 1
AT TELEPHOTO END